X-Ray Resonant Scattering from Magnetic Multilayers

A Photon-In/Photon-Out Way to Obtain Optical Constants

An international team of researchers from France, Italy, Sweden, and the USA working at the Advanced Light Source at Lawrence Berkeley National Laboratory has used resonant scattering of circularly polarized soft x rays to measure the optical constants (dispersive and absorptive components of the index of refraction) of iron near iron absorption edges in iron/vanadium magnetic multilayers. The optical constants measure the response of a material to excitation by electromagnetic radiation and are therefore needed to fully reconcile theoretical models with the results of experiments aimed at understanding and eventually controlling the behavior of magnetic multilayers.

Magnetic multilayers are currently the focus of considerable activity owing to potential applications for high-density magnetic data-storage systems. In the experiments on Beamline 6.3.2 at the ALS, the researchers used a model system composed of alternating iron (ferromagnetic) and vanadium (normally nonmagnetic) layers, each about 15 angstroms thick. Applying the Bragg equation for x-ray diffraction to multi-layers, the reflectance of the multilayers is a maximum (Bragg peak) at an angle determined by the thickness of an iron/vanadium layer pair (30.6 angstroms) and the wavelength. Resonant scattering occurs when the wavelength is near an absorption edge and results in enhanced reflectance and a shift in the position of the Bragg peak.

X-ray absorption directly yields the absorptive (imaginary) component β of the complex index of refraction $n = 1 - \delta - i\beta$. Absorption can also indirectly reveal the dispersive (real) component δ via a mathematical technique known as the Kramers-Kronig transformation, but this approach requires approximations and the introduction of arbitrary parameters. However, detailed measurements of the angle at which the Bragg peak is a maximum as the wavelength (photon energy) changes in a region around the absorption edges can give a direct measure of the real part of the index of refraction. Known as anomalous diffraction when applied to crystals, it has also been used for multilayers for many years.

What the international group working at the ALS did was use circularly polarized light (light with a helicity or handedness owing to a rotating polarization vector) on a magnetized sample with the magnetization vector in the plane of the layers. Working at wavelengths around the absorption edges for 2p core electrons in the iron (the L_3 and L_2 edges), they made measurements with the magnetization either parallel or antiparallel to the helicity of the light, in this way extracting the optical constants for both orientations. From this data, they then obtained all the components of the dielectric tensor, which is the quantity that reflects the response of the material to electromagnetic fields. In particular, the diagonal elements give the response of the material to unpolarized radiation, while the off-diagonal elements are directly related to the magnetic properties of the sample.

X-ray magnetic resonant scattering complements other techniques, such as x-ray magnetic circular dichroism, x-ray magneto-optic rotation (Faraday and Kerr effects), and interferometry. Each has its own set of challenges, and taken together, all these methods provide a complementary set of tools for studying magnetic multi-layers. Features of resonant magnetic scattering are that it is a photon-in/photon-out technique that is able to probe into the bulk of sample, giving information, for example, about buried interfaces. It is also possible to obtain element-specific hysteresis loops, even for diluted systems. Recently, another group demonstrated that resonant magnetic scattering is sensitive to the magnetic depth profile within a single layer.

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M. Sacchi, C. Hague, L. Pasquali, A. Mirone, J.-M. Mariot, P. Isberg, E.M. Gullikson, and J.H. Underwood, "Optical Constants of Ferromagnetic Iron via 2*p* Resonant Magnetic Scattering," *Phys. Rev. Lett.* **81** (1998) 1521.

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X-RAY RESONANT SCATTERING FROM MAGNETIC MULTILAYERS

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- **Magnetic multilayers exhibit giant magnetoresistance effect**
  - *Read heads for high-density magnetic data storage*
  - *Proposed magnetic memory chips*
  - *Fundamental physics*
- **Optical constants needed to reconcile theory and experiment**
  - *Dispersive (real) and absorptive (imaginary) parts of index of refraction*
  - *Determine response of multilayers to electromagnetic fields*
- **X-ray resonant magnetic scattering, a tool to measure optical constants**
  - *Full dielectric tensor is obtainable, avoiding Kramers-Kronig analysis*
  - *Magnetic effects can be extracted (element-specific hysteresis loop, magnetic depth profiling)*
  - *Photon-in/photon-out for probing bulk and/or buried interfaces*
- **Demonstrated on Fe/V multilayers**

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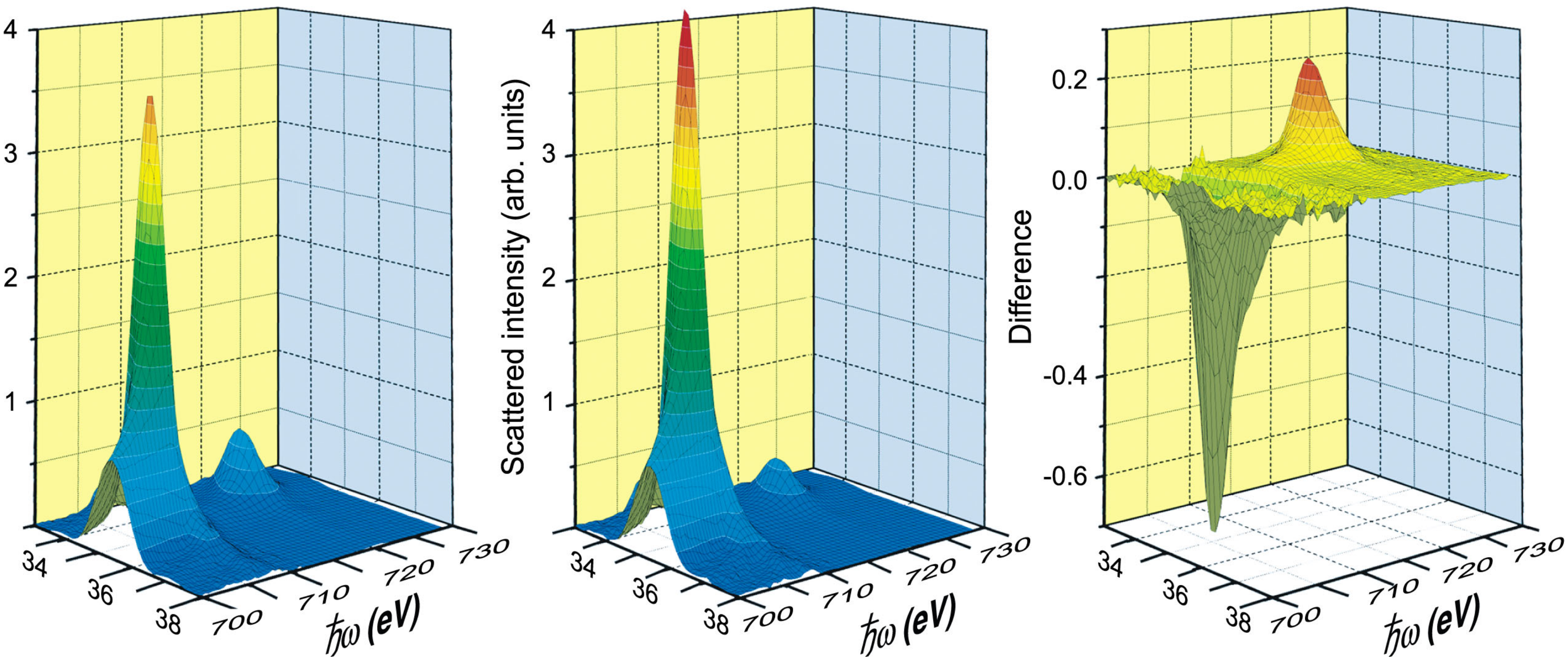

The optical constants are derived from the angles at which the resonant Bragg peak is a maximum for parallel (left) and antiparallel (center) orientation of the sample magnetization and helicity of circularly polarized soft x rays. The observed difference (right) is related to the magnetic properties of Fe in the Fe/V superlattice.

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